Fuel Moisture Sampling Guide

April 2003

Bureau of Land Management
Utah State Office

324 South State St.
Salt Lake City, Utah 84111

801- 539-4129

Prepared by Jolie Pollet
Utah State BLM Fire Ecologist

Table of Contents

Introduction

The strong influence that variations in live and dead fuel moisture content have on fire behavior has been recognized by wildland fire managers. Fuel moistures help drive fire suppression staffing and funding decisions; and guidelines for prescribed burning call for accurate values for the moisture content of fuels (USDI 2000). The National Fire Danger Rating System (NFDRS) uses or calculates as many as five fuel moisture contents. Depending on the fuel model involved, BEHAVE (fire behavior modeling program) requires up to three dead fuel moisture values and may call for a live fuel moisture value as well. This handbook aims to synthesize the existing literature on fuel moisture into uniform sampling procedures for BLM units in Utah.

Although live and dead fuels are a major influence on fire behavior, they are only two of many fuel and environmental parameters affecting fire behavior. Consequently, live and dead fuel moisture alone cannot be used to adequately evaluate potential fire hazard and fire behavior. Used in conjunction with the effects of other fire behavior influences, knowledge of the values and trends of fuel moistures can greatly improve the accuracy of fire hazard, fire behavior, and fire effects predictions for use in fire suppression, fire prevention, prescribed fire activities, and fire rehabilitation.

For most fuels, no computational procedure yet developed is adequate to estimate their moisture content. Direct sampling of fuels is the best alternative. Regardless of the purpose of fuel moisture sampling, a standard procedure for collecting, processing, calculating and reporting the moisture content is greatly needed. Errors in estimating representative fuel moisture content on a site creep in during every step of the process if defined procedures are not followed. Further, the collection of appropriate material must be standardized if accurate estimates are to be achieved.

This handbook presents a standard procedure for collecting and handling samples from various fuel complexes, with particular emphasis on selected fuels in Utah's BLM-administered lands.

The basis of live fuel moisture causes some confusion among fire practitioners (i.e., how can fuel have more than 100% moisture?). Moisture content of wildland fuels is expressed in relation to dry weight, not just the proportion of water in the fuel. It is the dry material that provides the heat to evaporate water so that the fuel will burn.

The definition of moisture content used here is the ratio of the weight of the water contained to the dry weight of the material, expressed as a percentage. The simple formula for percent moisture content is:

$$\frac{\textit{Weight of water in sample}}{\textit{Dry weight of sample}}(100) = \textit{percent moisture content}$$

The objectives of fuel moisture sampling and reporting are to:

- Assist in fire behavior predictions for wildfires and fire use
- Provide a basis for severity funding
- Determine whether a site is in prescription for prescribed burning
- Aid in determining post-fire resource effects
- Determine drought or drying trends
- Validate NFDRS calculated outputs

Dead Fuel Moisture

Dead fuels consist of: small to large diameter down and dead woody fuels (1-, 10-, 100-, and 1000-hr fuels); dead grasses and forbs; and surface litter such as fallen leaves and needles. Duff and soil are also categorized as dead fuels for the purposes of this guide.

Small diameter dead fuels typically carry the fire and determine the rate of spread and intensity, so their moisture content is extremely important. One-hour fuels can be estimated from environmental conditions (Fire Behavior Field Reference Guide 1992). Ten-hour fuel sticks are standard at all NFDRS sampling stations and provide a relative measure of drying. They may not be accurate enough to use as an indicator of 10-hour fuel moisture for prescribed fire implantation.

Duff may be sampled to determine its moisture content. The NFDRS uses duff moisture at a depth of 4 inches and greater below the surface as one measure of 1,000-hr fuels (Deeming et al. 1977). Many vital plant parts – rhizomes, roots, tubers – reside in duff.

Although soil is not usually considered to be a fuel, some surface soil samples are often collected for moisture content because sprouting parts of many plant species are concentrated in the surface of the soil rather than in the duff. Additionally, most BLM sites in Utah have very little or no duff and soil moisture content may be the best way to evaluate the effects of fire below the surface of the ground.

Live Fuel Moisture

Live fuels consist of: conifer needles; twigs and leaves of shrubs (evergreen and deciduous); and green (live) grasses and forbs.

Changes in live fuel moisture content are related to the physiological activity of the vegetation, and this activity is greatly influenced by soil moisture and the temperature of the soil and the air. When precipitation is deficient, less new growth is produced and peak moisture in the living material can be less than during more moist years. If soil moisture deficiency persists through the summer, live fuel moisture can drop more rapidly.

Soil and air temperatures affect the time new growth starts and the level of moisture attained by the vegetation. In situations when soil moisture is not limiting, new growth will start earlier and often reach a higher level of moisture when the weather in late winter and spring is warm than when the weather is cold. Other factors that affect soil and air temperatures, such as slope, aspect, and elevation also affect the amount of new growth, the timing of growth, and the level of moisture in the living material.

The moisture patterns of different plant species vary, particularly evergreen plants versus deciduous plants versus conifers. Moisture variations are also found between plants of the same species in the same locale and often in material taken from different heights and aspects on the same plant. Site quality also affects live fuel moisture; shrubs on good sites tend to produce more new growth, have higher moisture levels, and decrease in moisture more slowly during the summer than shrubs on poor sites. (Countryman and Dean 1979).

Live plants may either suppress combustion or contribute to it, depending on their moisture content and flammability of chemical compounds contained in the plant. The NFDRS uses weather variables to estimate the moisture content of shrubs and herbaceous plants. These are then used in calculating the ignition component, spread component and energy release component. However, previous experience has shown that moisture content in live vegetation is controlled by species physiology and time of year and may not be accurately calculated from such external variables.

Getting Started Sampling Fuel Moisture

For purposes of establishing trends in moisture content, the principles applied in sampling and monitoring fuel moisture are similar to those used in fire weather observations. Fire weather observations are made at stations elected as being typical in weather characteristics of the geographical area of interest. Because of the geographical variability of local weather, observations at the station at any given time are not likely to correspond precisely to weather conditions at other points within the area. Therefore, a weather observation at the station is actually only a sample of the weather for the larger geographical area.

Observation of fuel moisture requires an area of a few acres that is deemed representative of a more extensive geographical area. Samples of fuel are then collected from this small area for moisture determination. Thus, the fuel moisture sampling area serves the same function in fuel moisture monitoring as does the weather station in the monitoring of fire weather. Like the fire weather sample, the fuel moisture sample may only approximate the fuel moisture conditions over the larger geographical area because of the spatial variations in factors influencing fuel moisture.

Comparability of fire weather observations and indices is affected by standardization of weather instruments, the exposure of these instruments to weather conditions, observation procedures, and the specific time that observations are made. Spatial and temporal comparability of fuel moisture observations is achieved by standardization of fuel sample collection and moisture determination procedures and by specification of sampling conditions.

Site Selection for Establishing Seasonal Trends

Establishing a system for observation and monitoring of fuel moisture first requires the selection of areas for which moisture information is desired, including areas scheduled for prescribed burn activities. Climatic variation is the primary parameter to consider in setting the boundaries of these areas.

Sites may be selected with interagency partners to capture variation in fuels, climate and geographic area. The intent is for area coverage obtained through interagency coordination and collection, preventing duplication of efforts and minimizing time spent traveling and sampling. Year-to-year comparison of fuel moisture levels and trends is an important function of all sampling areas. Therefore, sampling areas should be located on sites that are not likely to be disturbed over a period of years.

A particular site should be representative of the live fuel complex of concern. The site should be relatively undisturbed, such as by heavy grazing or fuel manipulations, unless that is highly representative of the fuel complex. The species collected should be the main carrier of fire or the one that is most representative of all the species in a complex. If two species are of concern, they could both be sampled for the first or several years, to determine if the moisture cycle of one represents both. Because moisture cycles of deciduous vegetation is very different from evergreen vegetation, both may need to be collected to accurately represent a site.

The site should be located near a RAWS or in an area with weather data collected by a nearby automatic or manual weather station. Location of the site near a weather station allows for study of the long-term correlation of fuel moisture cycles to weather.

The sampling site or plot should be about 5 acres in size, and relatively homogeneous in terms of species composition, canopy cover, aspect, and slope steepness. It should be fairly easy to travel to and access, although collection should occur away from roadsides or water bodies.

Samples should be collected throughout the sampling area adhering to local protocol. For example, if a selected species is only located in a few spots on the site, it should be determined if individual samples will be collected in each location or if composite samples will be made.

Establish a photo-point by placing a permanent steel post at a location near the center of the plot. Photos should be taken of the general setting of the site looking in the four cardinal directions from the photo-point. Inclusion of a brightly colored, vertically placed meter stick will aid as a size reference for the vegetation. Photos looking downwards toward the fuels in four directions will also be useful for characterizing surface vegetation, litter and the amount of exposed soil.

Site Selection for Prescribed Fire

If sampling is being done in conjunction with prescribed fire activity, fuel samples should represent the project area, spanning the range of conditions, elevations, positions, and situations at the prescribed fire site. If the fuels surrounding the prescribed fire area are notably different from those within it, the surrounding fuels should also be sampled. Differences in anticipated fire behavior within and outside the intended fire area help to determine the needed contingency suppression resources in case the fire escapes.

Personnel for Fuel Sampling

Regardless of the reason for determining fuel moisture content, the sampling must follow standard techniques. Specific procedures for collecting live fuels must be determined for each species. Sloppy sampling and handling procedures can lead to poor results or serious mistakes. Only trained, skilled people should sample and handle the fuels and they must adhere to the procedures outlined in this guide. Greater consistency of results is often achieved when the same person or small crew does all the sampling in a given area.

Sampling Period and Frequency

For information to be used to determine trends or as input to the NFDRS, fuels must be sampled throughout the fire season, beginning in the spring and ending in the fall when no possibility of fire remains. This permits monitoring of fuel moisture from dormancy to peak moisture, through the decline of moisture during the summer, and into the often critically low moisture period in the fall. The standard time for NFDRS weather observations is at 1400 LDT (Local Daylight Time), usually the warmest part of the day. Fuel moisture samples should also be collected near this time. Moisture content of live fuels, soil, and 1000-hr dead fuel change slowly, therefore sampling periods about 10-15 days apart normally will be sufficient to indicate moisture trends; however, additional samples during prolonged heat waves or following precipitation may be desirable.

The seasonal period and frequency of sampling before prescribed burning is different for each situation. Valuable information may be obtained by sampling live fuels throughout the fire season a year or more prior to a prescribed fire. This can be particularly important if the seasonal pattern and range of values of foliar moisture for key species are unknown. If a fire must be conducted during a particular part of the season, fuels need be sampled only before and during that period until prescribed fuel moisture conditions are met. If the prescription requires a specific set of weather and fuel moisture conditions, then sampling should begin a few weeks before the prescribed fire is likely to be burned.

The Number of Samples to Collect

Sampling costs time and money, but so do errors in estimating how a fire will behave. The variability of the moisture content of a particular fuel across a burn unit at any given moment, along with the required precision, combine to determine how many samples are needed. See Appendix A for more detail and a worksheet to determine the number of samples to collect. This worksheet is recommended for field units in Utah, but not required.

If you are unable to collect the number of samples that the worksheet recommends, the Utah State Office suggests taking the following number of samples:

- Dead Fuels – 3 to 5 samples of each size class material of interest
- Live Fuels – 5 to 15 samples of each species of interest

Equipment Needed for Sampling

Refer to Appendix B for suggestions and estimated prices for equipment, and for a list of possible vendors to purchase equipment.

Containers

Containers for fuel moisture samples should have tight-fitting lids, be rust-proof, be numbered, and be of a material that can be put directly into a drying oven. Recommended containers are plastic bottles/jars that can tolerate high temperatures and have tight fitting lids that prevent moisture loss. Metal soil sample cans and zippered self-sealing bags made specifically for fuel moisture sampling are also available. However, metal cans made of steel aren't recommended because they can rust and the lids often don't seal properly; aluminum sample containers work well. The bags aren't recommended because they can be used only one time for sample collection, the bags may tip in the oven, they may not seal properly, and they are less cost-effective than the reusable containers. Containers should be marked with sequential numbers. Number containers and their corresponding lids by etching, stamping or with a permanent marker. Each lid and each container pair should be marked with the same number. Each empty container plus lid should be weighed together, to the nearest 0.1 gram of the weight of the empty, clean container and the identification number and weight permanently recorded in your files. Empty containers should also be weighed periodically to ensure the weights don't change.

Although metal cans are not recommended, many areas may already have a supply. To avoid spilling and escape of moisture, seal the lids of metal cans by using ½-inch drafting tape. Masking, electrical, and shipping tape may leave a residue that is hard to remove and may affect tare weights. Plastic containers with screw-on tops and fuel sample zipper bags do not need to be sealed with tape.

Clippers

Good quality pruning shears with two curved sharp blades are most effective for clipping fuels. At least two pair should be available. Sharpening may be necessary during the field season.

Garden Trowel

A trowel with a heavy shank and a sharp blade is used for duff and soil moisture sampling.

Carrying Case

A carrying case should be used for samples and equipment. Insulated plastic coolers with a handle work well and can keep samples from losing moisture on hot, sunny days. Between sampling periods, keep all sampling equipment, supplies and extra forms in the carrying case.

Drying Oven

An electric oven specifically designed for drying samples should be obtained. The best type is a forced-air convection oven (also known as a mechanical convection oven) with a fan to circulate the heated air. The oven must be able to maintain a regulated temperature of 100° C. A thermometer should be kept in the oven to check the actual temperatures. The size and cost of ovens varies; use the oven that best suits the number of samples you expect to dry at any one time. The use of a Computrac moisture analyzer is not recommended because it can handle only one very small sample at a time. Gravity convection ovens are not suggested because of their inability to regulate temperatures throughout the oven and the time required to heat the oven. However, many units may have already purchased gravity convection ovens (these cost significantly less than mechanical convection ovens) and they can be used, but numerous or very wet samples may require longer drying times.

Pre-owned, used and reconditioned laboratory mechanical convection ovens may be purchased at a significant discount from many vendors advertising on the internet.

Scale

A scale is needed for weighing the samples. The same scale should be used both times the sample is weighed. A top-loading electronic scale capable of accurately measuring to the nearest 0.1 gram is adequate. These scales allow rapid weighing and are inexpensive. Battery operated models for field use are available.

Understanding Plant Phenology of Selected Species to Aid in Collecting Live Fuel Moisture Samples

Phenology is the study of the annual cycles of plants and animals and how they respond to seasonal changes in their environment. For example, in botany, phenology refers to the timing of flower emergence, sequence of bloom, fruiting, and leaf drop in autumn. For the purposes of live fuel moisture sampling, it is helpful to have an idea of the plant phenology of your particular species of interest. Typically, herbaceous and deciduous vegetation has the most moisture in late spring and becomes drier through the summer and into the fall. Surges in live fuel moisture may occur in some species in late summer or early fall when significant precipitation occurs. Seasonal patterns of soil moisture vary by species. Moisture levels of conifer needles are lowest in the spring.

Most major changes in the moisture content of live plants are associated with physiological events in their annual life cycles. Noting the occurrence of these events each time a live fuel sample is collected gives you useful information for describing their flammability and for comparing physiological responses from site to site or from year to year. The kinds of events that should be recorded include:

Trees and Shrubs (including pinyon pine, juniper, sagebrush, oakbrush):

- Beginning of new foliage and stem growth
- New growth complete – new stems darkening, mature foliage present, terminal bud development at the end of the current year's shoot
- Presence of flowers (i.e., green or yellow sagebrush flowerheads), or ripe fruits (i.e., acorns)
- Autumn leaf color (for deciduous shrubs)
- Foliage falling off twigs (for deciduous or evergreen trees and shrubs)

Forbs and Grasses:

- Sprouting of plants
- Plants attaining full size
- Presence of seed heads or ripe fruits
- Cured foliage

Following are summaries of phenology for selected plant species that are most commonly sampled for live fuel moisture in Utah. This may aid sampling personnel in identifying the stage of plant development. The following descriptions were obtained from the Fire Effects Information System (FEIS 2003) and from personal comments from plant ecologists (Kitchens 2002, Tausch 2002).

Sagebrush

This general sagebrush discussion is inclusive of most sagebrush species commonly sampled in Utah (basin big sagebrush, Wyoming big sagebrush, mountain big sagebrush and black sagebrush). Sagebrush are considered evergreen and keep foliage year-round. Sagebrush start leaf and stem growth when temperatures warm and snow melts in the spring and early summer. Growth will continue to occur until temperatures rise too high or soil moisture becomes too low to support respiration.

In some sagebrush species, two kinds of leaves will form – ephemeral leaves and persistent leaves. These two types of leaves occur side-by-side on the sagebrush plant, but ephemeral leaves are larger and are produced earlier than persistent leaves. As moisture becomes limiting in the summer, ephemeral leaves will be shed while most persistent leaves are kept. If temperatures are too hot and soil moisture is deficient, some persistent leaves from sagebrush may also begin to shed and some stem death may occur. It is unusual for entire sagebrush plants to be killed outright by lack of moisture or very high ambient temperatures.

In the late summer or early fall, when temperatures moderate and precipitation increases, sagebrush will produce flowerheads. New leaf and stem growth in the late summer or fall will be insignificant compared to spring leaf and stem growth. In the late fall when temperatures drop, sagebrush respiration will cease.

Pinyon pine and Utah juniper

Pinyon pine and Utah juniper (pinyon-juniper) are physiologically similar enough to discuss together, although they should be sampled separately for live fuel moisture sampling. Pinyon pine and Utah juniper are evergreen species that keep green foliage year-round. Pinyon and juniper start foliage and stem growth in late spring or early summer and continue to grow until soil moisture becomes limiting – usually in middle summer (July to August). Starting in late summer, juniper will shed their older leaves on the interior of the plant.

Conifer species retain their needles for several years. In the intermountain west, the lowest moisture content of needles formed in previous years is in late spring-about the same time as when buds are breaking and new needles and twigs are beginning to form. Moisture content of old needles increases until late in the growing season, reaching their highest level in late summer, while moisture content of new foliage declines during the same period of time.

As the summer progresses into fall, live fuel moisture will continue dropping in pinyon and juniper. Follwing periods of significant precipitation, short-term surges in live fuel moisture can be expected; if moisture gets to the roots it will get to the foliage. However, no new growth will occur outside of the initial late spring/early summer growth period. On your sampling sheets, notation of juniper berries or pinyon cones is probably not useful since these structures grow and remain on the trees for a few years.

Successive years of drought may be sufficient to cause mortality in pinyon and juniper. Pinyon pine appear to be more sensitive to drought-induced mortality because they are less capable of shedding foliage and large branches. Drought-induced stress may also lead to increased insect and disease activity.

Gambel's oak

Gambel's oak is a deciduous shrub that loses its leaves in the fall and new leaves grow each year. New leaf and stem growth generally start occurring in late spring. Spring or summer frosts may result in significant mortality or stunting of growth in maturing oak leaves. Growth continues until late summer or early fall when moisture becomes limiting.

Collecting Fuel Samples

Material to be Sampled

The goal is to sample the moisture content of the materials that influence the way a fire will burn in those fuels. Selecting fuels to sample varies with the reason for sampling and the fuel type. Guidance in choosing the fuels to be sampled may be gained from research, previous experience, experts, direct observation, or other sources.

The fuels to be sampled and processed may include one or more of the following:

1. Dead Fuels
    - Small diameter down and dead woody fuel, 0 – ¼ inch in diameter (1-hour fuels)
    - Branch wood down and dead woody fuel, ¼ - 3 inches in diameter (10, and 100-hour fuels)
    - Large dead and down woody fuel 3+ inches (1000-hr fuels)
    - Duff and soil
    - Dead grasses, forbs
    - Surface litter, such as fallen leaves and needles

2. Live fuels
    - Foliage and twigs of juniper
    - Twigs and leaves of shrubs (evergreen and deciduous)
    - Green (live) grasses and forbs

Sampling Methods for Dead Fuels

Collecting the Sample

On arrival at the sampling site, place the sample case in the shade and prepare the field data sheet. Record the site name, date, time, name of observer, weather observations and container numbers.

Do not collect dead fuels if water drops from rain or dew are present on material because the presence of free surface water will cause large errors in calculated moisture content. Shaking the sample to remove excess water or attempting to dry the sample in any way is ineffective. Return to the site later in the day or the next day to collect the samples.

Keep the samples in the sampling case cool and dry until they are weighed. Samples may be refrigerated for up to 24 hours if they cannot be weighed the same day as collected.

Fuel Sampling Guidelines

1- and 10-Hour Fuels

Samples of 0- to ¼-inch and ¼ to 1-inch-diameter down and dead woody fuels should be taken from several twigs and branches resting on the ground. Do not collect the entire sample from one location or from a single branch. Collect twigs of as many sizes as possible within the size class. All samples must be collected from dead wood that is detached from its growth point. Do not collect parts buried in the litter, duff, or soil. Do not collect dead branches attached to the base of live trees or shrubs.

Cut several 1- to 1½-inch-long sections from each 0- to ¼-inch diameter down, dead twig or branch and collect in the sampling container. Collect only one piece from each ¼- to 1-inch down, dead branch and put in the sampling container or a plastic zip-lock bag. Remove all lichen or other debris and very loose pieces of bark from the samples. The wood collected does not have to be completely sound but should not be decayed to the point of being easily rendered into powder or splinters when rubbed. Some splitting caused by drying is acceptable. Wood in various stages of decay should be collected in proportion to its presence on the site, as long as the rules just stated are followed. Place the collected samples in the carrying case.

100- and 1000-Hour Fuels

Samples of 1- to 3-inch and 3+-inch-diameter down and dead woody fuels should be taken from one or more branches resting on the ground (depending on the availability of sampling material). All samples must be collected from dead wood that is detached from its growth point. Do not collect parts buried in the litter, duff, or soil. Do not collect dead branches attached to the base of live trees or shrubs. Do not sample from branches or logs that have recently fallen.

For 100-hour fuels, select a sound branch (1- to 3-inches in size) and slice out one or more wafers less than ½-inch thick, starting at least six inches from the end of the branch. For 1000-hour fuels, select a sound log 3- to 8-inches in diameter and slice out one or more wafers less than ½-inch thick, starting at least six inches from the end of the branch. Use a hand saw for cutting wafers – oils from chainsaws may affect the dead fuel moisture results. Each wafer is considered one sample. Remove all lichen or other debris and very loose pieces of bark from the samples. The wood collected does not have to be completely sound but should not be decayed to the point of being easily rendered into powder or splinters when rubbed. Some splitting caused by drying is acceptable. Wood in various stages of decay should be collected in proportion to its presence on the site, as long as the rules just stated are followed. Place the samples in a sealed plastic zip-lock bag and place the bag in the sample carrying case.

Some other ways for measuring 100- and 1000-hour fuels are to: use a moisture probe that can be inserted into branches and logs; using a large drill bit to obtain wood particles that can be dried and weighed; chopping up a wafer obtained from a branch or log and putting it into a sampling container to be dried and weighed; or placing an oven-dry piece of branch or log wood of a known dry weight on a site to measure increases in fuel moisture (similar idea to the 10-hour fuel sticks). If consistently followed, these methods may all be acceptable. Be sure to note the sampling method used in the remarks section on the data collection forms.

Duff and Soil

Moisture content of duff and soil has important influences on the depth of burning below the ground surface. Duff and soil must be sampled carefully and selectively if the impacts and results of the fire are to be predicted well. For duff and soil samples, the depth of the sample is very important and should be measured, not estimated. The base of the litter layer is a reference point for the duff depth and the base of the duff layer (if there is a duff layer) is a reference point for the soil depth. It may be necessary to collect several duff or soil samples at a site and at different depths to accurately reflect moisture conditions. Select sampling spots that are representative of the area.

The duff layer can be differentiated from the litter and soil layers because the plant material in the duff layer is so decomposed that the plant species are not readily identified. Another common characteristic of the duff layer is the presence of a dense network of very fine, hairlike strands (fungal hyphae). Mineral soil can be detected by rubbing questionable soil between your fingers. Soil particles can usually be felt and may be fine enough to fill the indentations in your fingertips.

Remove all live plant stems, roots, or other parts of living plants, and animal droppings from the samples. Be careful to avoid including mineral soil in the duff sample (and vice versa) and also avoid stones in the sample. Place the sample in a sampling container with a lid.

Dead Grasses and Forbs

Collect the sample from 15 to 20 plants. Clip dead blades or vegetation from all vertical portions of tall grasses/forbs and tops and sides of smaller bunch grasses or smaller forbs. Collect blades or vegetation that are brown or tan, and not decomposed (or gray-looking). Collect an entire specimen and clip it into short pieces as you place it into the sample container.

Litter

Gather litter (whole, undecomposed leaves or needles) from both sunny and shady spots within an area. Collect only uncompacted dry litter. Place litter into the sampling container.

Sampling Methods for Live Fuels

Collecting the Sample

On arrival at the sampling site, place the sample case in the shade and prepare the field data sheet. Record the site name, date, time, name of observer, and container numbers.

Do not collect live fuels if water drops from rain or dew are present on leaves or stems because the presence of free surface water will cause large errors in calculated moisture content. Shaking the sample to remove excess water or attempting to dry the sample in any way is ineffective. Return to the site later in the day or the next day to collect the samples.

For live fuels, only the twigs and foliage should be put into the sample container. Remove any flowers, seed pods, nuts, berries and similar material. Also remove any dead material.

Plant material often becomes fairly stiff as it dries, and it may spring from the containers while in the drying oven. This makes the lid difficult to replace and some of the sample may fall out. For this reason, pack material loosely in the container. Never compress samples to get extra material in the container. However, collect an adequate amount filling the container about ¾ full. Cut the stems of each shrub and herbaceous plant into small pieces as they are dropped into the container. Cutting the plants into smaller pieces also allows a greater amount of material to fit into the container.

As you move about the site and collect material, replace the lid on the container to cover materials already collected. When the container is filled, immediately replace the lid tightly. Any comments or observations about plant phenology (as discussed previously) should be recorded in the remarks section on your field data sheet.

Keep the sample containers cool and dry until they are weighed. If the collected samples receive even moderate heat, some moisture will evaporate, vaporize and escape when the container is opened yielding an error. Samples may be refrigerated for up to 24 hours if they cannot be weighed the same day as collected.

Sampling Guidelines for Tree, Shrub and Grass/Forb Fuels

Juniper Trees

Using clippers, clip the foliage (needles) into the sampling container. In the container, clip a mixture of new and older growth and take material from all sides of trees. Foliage from more than one tree can be in the same sample container. Several trees should be sampled at different heights on the trees and at different aspects. Only collect foliage, not stem material from trees. Do not include dead or diseased foliage, cones, or berries in any stage of development. Fill sampling containers about ¾-full.

Conifers (Pinyon pine and Douglas-fir)

Using clippers, clip only the needles formed in previous years, but not foliage from twigs so old that they are thickened or woody. Don’t collect new year’s growth as those fuel moisture values don’t adequately reflect the majority of foliage from the tree. Foliage from more than one tree can be in the same sample container. Several trees should be sampled at different heights on the trees and at different aspects. Only collect foliage, not stem material from trees. Do not include dead or diseased foliage, cones, or berries in any stage of development. Fill sampling containers about ¾-full.

Shrub (sagebrush, Gambel's oak, or other shrubs)

Using clippers, clip the foliage and pliable small stem material into the sampling container. In the container, clip a mixture of new and older growth and take material from all sides of shrubs. Foliage from more than one shrub can be in the same sample container. Several shrubs should be sampled at different heights on the shrubs and at different aspects. Eliminate all dead twigs or twigs with diseased or insect-infested foliage. Do not include flower buds, flowers, seed pods, or berries in any stage of development. Fill sampling containers about ¾-full.

Grass/forb

For grasses, collect only the leaves; do not collect seedheads. Do not collect stems, seed heads or succulent white or pale-green leaf bases. For tall grasses, clip the leaves from all vertical portions of the plants cutting the blades near their point of attachment to the stem. For smaller grasses, clip blades of different lengths; include only the leafy material and not the base of the leaves. Clip the material into pieces to fill sampling containers about ¾-full.

For forbs, collect the entire plant of small, single-stemmed forbs by clipping the stem at ground level. If a species has multiple stems, cut one stem with leaves from each plant. Remove and discard all flowers and fruits in any stage of development from all herbaceous plants. Clip the material into pieces to fill sampling containers about ¾-full.

Drying the Samples

Preheat the drying oven to 100°C. Transfer the information from the field data sheet to the calculation sheet. Adjust the scale to zero. Place a closed container on the center of the scale platform. Read the scale and record it as the "wet" weight on the calculation sheet. Check to see that the identification and contents of the container match those recorded on the field and calculation sheets

Repeat this procedure until all samples are weighed. Be sure to set the scale to zero before each sample is weighed because the adjustment can be changed by minor vibrations and movement of the scale, causing errors.

Remove the lid as you put the sample in the drying oven. If any sample material falls out when placing it in the oven, throw this material away and weigh the sample again.

Space the samples evenly in the oven so that air circulates freely around every container. If few samples are being dried, center them on the middle rack of the oven. Record the date and time that the samples were put in the oven.

For 100-hour or 1000-hour samples, remove the wafer from the plastic bag and weigh it. Place the wafer directly on the rack in the oven and dry and weigh as you would for samples in containers.

Dry the sample for 24 hours at 100°C. Large samples of very wet fuels should dry 48 hours. Do not put additional samples into the oven while drying a set of samples. If you do, the original samples will absorb moisture from the new samples and must then be dried an additional 24 hours. To be sure a very wet sample is sufficiently dry (especially for 1000-hr fuels), you may weigh after 24 hours then dry for an additional 12 hours. If the weight doesn't change, the sample is dry. If the weight changes, continue to dry until the sample does not lose additional water weight.

At the end of the required drying time, take the samples from the oven and quickly replace the matching lid tightly as each container is removed. This prevents the absorption of moisture from the air. Do not leave the oven door open. It should be opened only long enough to remove a few samples, because moisture from the room will enter the oven and can quickly be absorbed by the dried samples inside. Enough moisture could easily be added to the samples to cause a significant error. If any sample material falls from a container during the drying process, throw the sample away unless you know which container it fell from and you can replace all of it in the right container.

Check the container number and its contents before you record the dry weight on the laboratory sheet. Check the scale for a zero weight setting before weighing the next sample.

After each dried sample is weighed, replace the lid tightly on the container and save the sample until the fuel moisture content is calculated. If an obvious error appears in the calculation, the sample can be weighed again and the source of the error may be found. Once fuel moisture calculations have been made, discard the sample and clean the containers for reuse. Wiping with a clean rag is sometimes enough to clean the containers, but they may need to be washed and scrubbed to remove plant residue. Containers must be free of soap residue and completely dry before the lids are replaced and the containers are stored for future use.

Calculating Moisture Content

The formula for calculating percent moisture content is:

$$\frac{\textit{weight of water in sample}}{\textit{dry weight of sample}}\ (100) = \textit{percent moisture content}$$

This is most easily done by the following formula:

$$\frac{\textit{wet weight of sample} - \textit{dry weight of sample}}{\textit{dry sample weight} - \textit{container tare weight}}\ (100) = \textit{percent moisture content}$$

Use the excel spreadsheets found in the enclosed CD to greatly increase the speed and accuracy of the calculations. Whether the computations are done by hand, calculator, or computer, consider repeating the calculations to be sure they are correct. One of the most common sources of error while processing samples involves these calculations.

Guidelines for Fire Behavior and Tactics Based on Live Fuel Moisture Values

The following guidelines were developed by Nevada BLM (www.nv.blm.gov/fuels/). The break-points were developed from years of past fire and fuels observations. Although the break-points were created for the BLM in Nevada, they may be able to be applied to fuels and fire behavior in Utah. Use these break-points as guidelines and refine locally when appropriate. These break-points correspond to *live fuel moisture* values.

181% and Higher

Fires will exhibit VERY LOW FIRE BEHAVIOR with difficulty burning. Residual fine fuels from the previous year may carry the fire. Foliage will remain on the stems following the burn. Fires can generally be attacked at the head or flanks by persons using hand tools. Handline should hold fire without any problems. Fires will normally go out as soon as the wind dies down.

151% to 180%

Fires will exhibit LOW FIRE BEHAVIOR with fire beginning to be carried in the live fuels. Both foliage and stem material up to ¼-inch in diameter will be consumed by the fire. Burns will be generally patchy with many unburned islands. Engines may be necessary to catch fires at the head and handline will be more difficult to construct, but should hold at the head and the flanks.

126% to 150%

Fires will exhibit MODERATE FIRE BEHAVIOR with a fast continuous rate of spread that will consume stem material up to 2-inches in diameter. These fires may be attacked at the head with engines but may require support of dozers and retardant aircraft. Handline will become ineffective at the fire head, but should still hold at the flanks. Under high winds and low humidity, indirect line should be considered.

101% to 125%

Fires will exhibit HIGH FIRE BEHAVIOR leaving no material unburned. Frontal attack with fire engines and dozers will be nearly impossible on large fires, but may still be possible on smaller, developing fires. Aircraft will be necessary on all these fires. Flanking attack by engines and indirect attack ahead of the fire must be used. Spotting should be anticipated. Fires will begin to burn through the night, calming down several hours before sunrise.

75% to 100%

Fires will exhibit EXTREME FIRE BEHAVIOR. Extreme rates of spread and moderate to long range spotting will occur. Engines and dozers may be best used to back up firing operations, and to protect structures. Indirect attack must be used to control these fires. Fires will burn actively through the night. Air turbulence caused by the fire will cause problems for air operations.

74% and Below

Fires will exhibit ADVANCED FIRE BEHAVIOR with high potential to control their environment. Large acreage will be consumed in a very short time period. Backfiring from indirect line, roads, etc. must be considered. Aircraft will need to be cautious of hazardous turbulence around the fire.

Common Sources of Error

Field Errors

Some of the most common sources of error while collecting samples are:

- The samples are placed in a container with a different number than is listed on the field data sheet.
- An incorrect lid is placed on a container.
- The container number is recorded incorrectly on the data sheet.
- Drops of rain or other free water are allowed to fall into the container.
- Small rocks, animal droppings, and other material are included in the duff, soil, or litter samples.
- An inadequate amount of material is collected. (Fill the container at least ¾-full.)
- Failure to collect material from several spots, and plants on a site.

Laboratory Errors

Some of the most common sources of error in the laboratory are:

- Failure to check the container numbers against the sample contents as recorded on the calculation sheet.
- Some material falls out of the container while drying.
- Failure to set the scale to zero before weighing.
- The scale is misread.
- Errors are made during the entry of values into the calculator or while doing the calculations (this is possibly the greatest single source of error – double-check!)

Reporting Requirements for BLM Units in Utah

Sample on the 1st and 15th of every month (or as close as possible to these dates) starting in the spring and ending in the fall. Units may elect to sample more frequently rather than on the 1st and 15th of the month. This is acceptable as long as samples are taken at least two times per month during the fire season. Depending on the elevation of the site, sampling should begin as soon as snow melts or in March and continue through November or until the site is covered in snow.

Turn in Fuel Moisture Calculation Sheets via hard copy, fax or email to the State Office Fire Ecologist by the 2nd and 16th of every month, or as close as possible to these dates. If Units are unable to provide results, notify the State Office Fire Ecologist.

1. Fuel Moisture Site Description Form - Electronic Form on CD

1. Date ___________________________ 2. Observer __________________

3. Unit ____________________________ 4. Site Name or # ______________

5. Latitude ________________________ 6. Longitude __________________

7. UTM Coordinates _________________

8. Major Vegetation:

Tree species 1________________________ percent cover_____________
Tree species 2________________________ percent cover_____________
Tree species 3________________________ percent cover_____________
All other trees________________________ percent cover_____________

Shrub species 1________________________ percent cover_____________
Shrub species 2________________________ percent cover_____________
Shrub species 3________________________ percent cover_____________
All other shrubs________________________ percent cover_____________

Grass/forb species 1___________________ percent cover_____________
Grass/forb species 2___________________ percent cover_____________
Grass/forb species 3___________________ percent cover_____________
All other grasses/forbs_________________ percent cover_____________

9. Predominant aspect _____________ 10. Predominant % slope __________

11. Elevation (feet) _________________ 12. NFDRS fuel model ____________

13. Associated NFDRS or RAWS weather station number___________________________

14. Vegetation condition description of layer chosen for moisture sampling:

Average height (ft) _____________ Percent dead _____________

Continuity of layer ______________

15. Photo numbers and descriptions____

Remarks: ____

____

Instructions - Fuel Moisture Site Description Form

Instructions: Complete this site description form after the site has reached full greenup. Take digital photos of the area on the same day the site is described.

1. Enter the date of this observation.

2. Enter the observer's name so there is a contact for questions.

3. Enter organizational unit by name (ex. Salt Lake Field Office, Price Field Office).

4. Site Name descriptive of location (ex. Belle Creek) or site number.

5., 6., and 7. Enter latitude and longitude as displayed by GPS or as determined from a map. Include units such as -105.2425 degrees or -105^{o} 14.55 mins or -105^{o} 14 min 33 sec. Enter UTM coordinates from the GPS.

8. Enter the names of the predominant species on the site and the approximate percent canopy cover of each for the following: trees, shrubs, and herbaceous (grasses and forbs). Leave blank if type isn't present. For example, if there are no trees, skip the section on trees. If there are more than three species of a type on site, enter the percent coverage of all the remaining species of that type and list the other species (in no particular order). Also enter the percent cover of bare soil at this time of year, that is soil that is not covered by either live or dead plant material.

9. Enter the general aspect of the site as N, NW, W, SW, S, SE, E, NE.

10. Enter the average or most common percent slope on the site.

11. Enter the site's elevation in feet.

12. Enter the NFDRS fuel model that best represents the vegetation on the site.

13. Enter the NFDRS or RAWS weather station number associated with the site (if one is associated).

14. Describe the general condition of the vegetation layer that is being sampled for moisture content: average height in feet, an estimate of the average percent dead material in the plants, the continuity of the plant layer (continuous, patchy, isolated individuals).

15. Note the photo numbers/names and a brief reference to the scene pictured.

In the Remarks Section include any other information about the condition of this vegetation that has not been covered (i.e., grazing disturbance, insect: disease, activity, etc).

2. Worksheet for Determining Number of Samples

The following worksheets can be used to help determine the adequate number of samples to take. The first worksheet can be used to calculate the sample size, and the second worksheet is an *example* of how to use the worksheet to calculate sample size. The CD contains an excel version of this worksheet.

Worksheet to Calculate Sample Size

A. How many prefire samples have been collected?
n = ____________

B. How close must your value of fuel moisture content be for your intended project?
± _________percent

C. Using your prefire samples, list one set of collected moisture content samples below:

	x	**x^2**		**x**	**x^2**
1	_______	_______	11	_______	_______
2	_______	_______	12	_______	_______
3	_______	_______	13	_______	_______
4	_______	_______	14	_______	_______
5	_______	_______	15	_______	_______
6	_______	_______	16	_______	_______
7	_______	_______	17	_______	_______
8	_______	_______	18	_______	_______
9	_______	_______	19	_______	_______
10	_______	_______	20	_______	_______

D. Add all the values of x: Σx = ____________

E. Multiply each value by itself (x^2) and add all the values:
Σx^2 = ____________

F. Multiply the value in **D** by itself and divide by the value in **A**:
$(\Sigma x)^2/n$ = ____________

G. Subtract the value in **F** from the value in **E**: $\Sigma x^2 - (\Sigma x)^2/n$ =

____

H. Subtract 1 from the value in **A**: $(n - 1)$ = df = ____________

I. Divide the value in **G** by the value in **H**: $(\Sigma x^2 - (\Sigma x)^2/n) / (n - 1)$ =
s^2 = ____________

J. What is your acceptable moisture content error?
± ____________ percent

K. How sure (percent) do you want to be that you will be within your range of acceptable error? P = ____________ percent

L. Take the value in **K**, subtract it from 100, and divide the result by 100: $(100 - P) / 100$ = probability = ____________

M. Go to a t table and down the left-hand column under "df" to the value in **H,** and across to the right to the column under the probability value in **L**.

List the value at the intersection: t = ____________

N. Multiply the value in **J** by itself: E^2 = ____________

O. Multiply the value in **M** by itself: t^2 = ____________

P. Multiply the value in **I** by the value in **O** and divide by the value in **N**: $(t^2 s^2) / E^2 = m$ = ____________

Q. Round to the next highest integer: __________

This is the number of samples you must collect to be sure you will achieve your acceptable precision in estimating the moisture content of the selected fuel.

Worksheet to Calculate Sample Size-Example

A. How many prefire samples have been collected? n = 12

B. How close must your value of fuel moisture content be for your intended project? 1 percent

C. Using your prefire samples, list one set of collected moisture content samples below:

	x	x^2		x	x^2
1	7	49	11	7	49
2	9	81	12	6	36
3	8	64	13		
4	7	49	14		
5	6	36	15		
6	8	64	16		
7	9	81	17		
8	10	100	18		
9	9	81	19		
10	8	64	20		

D. Add all the values of x: Σx = 94

E. Multiply each value by itself (x^2) and add all the values:
Σx^2 = 754

F. Multiply the value in D by itself and divide by the value in A:
$(\Sigma x)^2/n$ = 94 x 94/12 = 736.3

G. Subtract the value in F from the value in E:
$\Sigma x^2 - (\Sigma x)^2/n$ = 17.7

H. Subtract 1 from the value in A: (n – 1) = df = 11

I. Divide the value in G by the value in H:
$(\Sigma x^2 - (\Sigma x)^2/n) / (n - 1) = s^2 =$ <u>17.7/11 = 1.6</u>

J. What is your acceptable moisture content error? ± <u>1</u> percent

K. How sure (percent) do you want to be that you will be within your range of acceptable error? P = <u>90</u> percent

L. Take the value in **K**, subtract it from 100, and divide the result by 100: (100 – P) / 100 = probability = <u>(100 - 90)/100 = 0.10</u>

M. Go to a t table and down the left-hand column under "df" to the value in **H,** and across to the right to the column under the probability value in **L**. List the value at the intersection: t = <u>1.796</u>

N. Multiply the value in **J** by itself: $E^2 =$ <u>1</u>

O. Multiply the value in **M** by itself: $t^2 =$ <u>3.23</u>

P. Multiply the value in **I** by the value in **O** and divide by the value in **N**: $(t^2 s^2) / E^2 = m =$ <u>5.2</u>

Q. Round to the next highest integer: <u>6</u>

This is the number of samples you must collect to be sure you will achieve your acceptable precision in estimating the moisture content of the selected fuel.

3. Fuel Moisture Content Form-Excel Version on CD

Agency	State	Field Office	Site Name/Number

Collection Record			Moisture Determination Record		
Observer	Date	Time	Observer	Date in oven	Time put in oven

Container Number	Species (Live) Size Class (Dead)	A Gross Weight Wet	B Dry	C Tare Weight	D Water Weight	E Dry Weight	F Percent Moisture

Sample Material Collected	Calculation Summary
Live Fuels [ ] Dead Fuels [ ] Leaf and Stem [ ] Leaf Only [ ]	A - B = D B - C = E (D / E) * 100 = F Average of Samples =

Weather (Optional)

Dry Bulb _______ RH _______% Wet Bulb _______ Cloud Cover _______

Please send to: Jolie_Pollet@blm.gov Wk: 801-539-4129 Fax: 801-539-4131 2nd and 16th of every month	**Remarks:**

Instructions for moisture content sampling data sheet

The form has room to enter 15 samples. You will need at least one copy of each form for live and dead fuel samples, but you may use more forms for differing vegetation types or when you take more than 15 samples.

1. Enter header information on each sample collection form:
   Agency
   State
   Field Office
   Site name or number

2. Enter **Collection Record** header information:
   Observer (your) name
   Date
   Time

3. Take a few moments to fill out the **Remarks** section with any phenological observations or other comments. Note anything unusual or of special interest about the site. Also note if you're collecting anything other than a *mix* of old and new growth for live fuel samples.

4. Mark the appropriate boxes for the type of sample material collected (live or dead fuels). For live fuels, mark whether you're collecting leaf and stem material or leaf material only.

5. Enter the **Container Number** as you select each from your pack or box.

6. If collecting only 1 species for live fuel moisture, note the species in the first row under **Species** heading. If you are collecting more than one, note species in each row. For dead fuels, note the size class (e.g., 1-hr, 10-hr, 100- hr, 1000hr, grass/forb, duff, soil, or litter).

Equipment Vendors, Suggested Equipment and Estimated Costs

Equipment Vendors

This is not a comprehensive nor inclusive list of all possible vendors for equipment. The BLM does not endorse any of these companies. This vendor list is only a sample of all the possible providers of equipment. You are encouraged to go beyond this list to find the best equipment at the best prices.

http://www.benmeadows.com (containers, clippers, scales, etc.)
http://www.forestry-suppliers.com (containers, clippers, scales, etc.)
http://www.daigger.com (new ovens)
http://www.bluem.com (new ovens)
http://www.seedburo.com (new ovens)
http://used-line.com (used ovens)
http://www.triadsci.com (used ovens)
http://www.bhiequipment.com/labware.htm (used ovens)

Suggested Equipment and Estimated Costs

- 8 oz. size, polypropylene jar with lid, heat-resistant, $3/ea
- Small pruning shears, $30/ea
- Insulated ice chest large enough to hold all samples, $40
- 2 to 4 cubic foot mechanical convection oven, $1,000 to $3,000
- 200-gram capacity scale with 0.1 gram resolution, $150